Malaysian Journal of Civil Engineering 29(2):216-226 (2017)

REVIEW PAPER

A REVIEW OF DOWNSCALING METHODS FOR CLIMATE CHANGE IMPACTS ON WATER RESOURCES

Nor Adilah Ahmad, Nur Ain Zakaria, Nur Nabilah Farhana Mohammad Fathilah & Ponselvi Jeevaragagam*

Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

*Corresponding Author: *ponselvi@utm.my*

Abstract: Measuring the impact of climate change on water resources is commonly based on downscaled simulations from global climate models (GCMs). The downscaling of GCMs is used to improve representation of climate data over a regional part which can be produced either by using a regional climate model (RCM) or statistical downscaling. Although both of these two techniques are common, but they are seldom compared. This study review the relationship between climate change and water resources, impact of climate change on hydrological system, and the discussion on several downscaling methods that are commonly used in the assessment of climate change impacts on water resources. Past studies have shown that climate change will directly affect water resources, and will result to increase or decrease of the water body on earth surface. This study found that statistical downscaling technique is more favourable and more efficient technique to assess the climate change impacts on water resources. However, it is still not clear which methods can give the most reliable estimates of projected climate change, since the modelling procedures of GCMs have their own strengths and limitations.

Keywords: *Climate change, water resources, global climate models (GCMs), downscaling*

1.0 Introduction

Climate change has relevant importance on water resources availability in the world. It is having very important issues regarding to the future water resources. Changes in temperature and increase of concentrations in greenhouse gases may affect the hydrology process, availability of water resources, and water use for farming, population, mining industry, aquatic life in rivers and lakes, and generation of hydropower. The rises in the surface temperature, alteration in precipitation patterns, and evapotranspiration rate caused by climate changes will accelerate the global hydrological cycle. According to IPCC (2013), the global climate simulations of precipitation are most likely will decrease in lower, mid and high latitudes. On the other hand, some results show that the drought increases from 1% to 30 % for warmer climate by 2100.

Projections of future climate and the significances for regional hydrology are very important for identifying proper mitigation and adaptation strategies under a climate changes. The most common tools for simulating complex climate processes are global climate models (GCMs). The typical horizontal resolution of GCMs is 200-300 km, which tends to greatly smooth the geographical features of the Earth's surface. Therefore, there is a need to obtain more detailed information when studying the regional scale impacts of climate change. Downscaling of GCMs, to improve representation over a limited region, can be done either by use of a dynamical downscaling or by statistical downscaling of the GCMs (Khan *et al*., 2006). Although both of these techniques are common, they are seldom compared. This paper investigates the effect of using different downscaling techniques for the assessment of climate change impacts on water resources.

2.0 Climate Change, Water Resources and Hydrological Cycle Relationship

Climate change has become one of great influences on water cycle, also known as hydrological cycle all over the world. Hydrological cycle and water resources are the most important aspects related to climate change. This is because of close relationship between both hydrology and water resources to the industry, city development and economic fields. The main reason on how climate change greatly affected the water resources is when there are changes in water body and water quality. The changes can be experienced because of climate factors such as rainfall intensity and especially the temperature changes.

With the presence of the climate change, it will directly affect the evaporation, runoff, and the soil humidity. It will also cause the current situation of hydrologic cycle to be interrupted and directly caused the reallocation of the water resources in time and space, which resulted to the changes of water supplies in human society and ecological system. However, at the same time the water resources system changes will affect the local climate, and will exacerbate climate change to a certain extent (Nan *et al*., 2011).

Many researches have been conducted since the increasing of climate change impact on the water resources. The issue was a priority for the public and led them to start the research of the impact of climate change on water resources at the early of 1980s. For example, from 1985 to 1987, World Meteorological Organization (WMO) has published a review regarding climate change impact and comes out with some tests and evaluation methods. Then, WMO published the analysis report of climate change impacts and even summarized the problems in water resources systems in line with future climate change (Houghton et. al., 1995; WMO, 1987).

After that, in 1999, a research on potential climate change impacts on water resources in the Auckland region (New Zealand) is assessed using scenarios of future climate change (in 2020, 2050, and 2100) and a daily water balance model to transform the scenarios into seasonal impacts on the soil water regime and catchment water yield. Differences in climate regimes and site characteristics are found important as the water yield results indicate an unambiguous change to increased yield, especially over winter, although with very large uncertainties concerning the magnitude of the change (Fowler, 1999).

3.0 Impact of Climate Change on Water Resources

Water is a fundamental element to human life and the most important natural resources in economic growth, social progress and agriculture development. It is not only necessity in both through direct consumption and use in agriculture but also in industrial activities (power generation, transportation, and waste management). As the water widely used for drinking purposes, the use of water for industrial purpose which is important to fuel economic growth must compete with the demands of household chores. Not only that, the availability of clean and safe water often is a constraint on economic development (Bigas, 2012).

Due to the changes of water accessibility, the competing demands may lead to the possibility of increasing the conflict over the water resources. In northern Kenya, Samburu people are having some difficulties to adapt with the changing rainfall patterns, the decreasing amount of rainfall plus the other pressures on the natural resources. This situation led to a worsening of the conflict between tribal groups over access to scarce water (Smith, 2006).

As for today without reliable water supply, there is a large number of people about one billion people still having shortage of enough safe water and more than two billion people lack safe sanitation (Hellmuth and Kabat, 2003). One of the most severe consequences of climate change will be the alteration of the hydrological cycle, and this will be greatly affected the quality and quantity of regional water resources (Raneesh, 2014). Studies to provide more accurate water flow prediction for both gauged and ungauged sites of the Upper Thames River watershed model are developed, using hydro-meteorological variables (Jeevaragagam and Simonovic, 2012 and 2013).

Generally, climate variability and change may affect both water quality and water quantity for the present and the future, which contribute to water scarcity described in more detail below.

3.1 Water Quality

The qualities of water bodies might be affected by climate change as the result of the changes in runoff, the pattern of transportation of agriculture, industrial or domestic pollutants and modification of the assimilation capacity of pollution by the water bodies related to changes in the temperature.

Actually, the water quality also can be affected both directly and indirectly by the climate change. Indirectly, climate change may cause an increase in runoff which contributed increase in pollution due to different reasons, such as erosion and transport of sediments, pollution by fertilizers and pesticides used in agriculture, or urban and industrial pollution. It can also result a decrease in runoff and may lead to indirect consequences on water quality, which are related to changes in the assimilation capacity of pollution by water bodies (Cunha *et al*., 2007)

Besides that, climate change also contributed to direct impact on water quality by the possibility of increasing water temperature which decreasing the actual level of dissolved oxygen in water and increase the released of phosphorus from sediments (Demuth and Radojevic, 2011). As a proof, Arheimer *et al*. (2013) found that the total mean load to the Baltic Sea may decrease for nitrogen and increase for phosphorus by 2100, as the consequences of climate change. Beare and Heaney (2002) also found that climate change can affected the water quality by increasing the river salinity. If there is a reduction in precipitation, the surface water runoff will immediately decrease, causing less water to dilute the existing levels of saline ground water discharge.

3.2 Water Quantity

The changes in precipitation and temperature are the sole key to the changes in the availability of water resources including surface and groundwater (Beare and Heaney, 2002). For example, Pungwe River Basin in Zimbabwe and Mozambique, the river flow and water availability have decreased due to a decreased in precipitation especially during the end of the dry season for about 50 to 60 percent which could led to severe other consequences (Anderson *et al*., 2011). Meanwhile at Mediterranean watershed, based on combined result from both Sado and Guadiana river basins, it can be noted that the precipitation and temperature, projected by the global climate models for the end of the twenty-first century, point towards greater reduction in the water availability (Mourato *et al*., 2015). Climate change also has the potential to impose additional pressures on water availability and water demand in Africa (Bates *et al*., 2008).

In Africa's large catchment basins of Niger, Lake Chad and Senegal, the total available water has already decreased by 40 to 60 percent, and desertification has been aggravated by lower than average annual rainfall, runoff and soil moisture, especially in Northern, Southern and Western Africa (Solomon, 2016). The consequences to water supply include low water flows in springs and rivers, and decreasing groundwater levels. Mourato *et al*. (2015) found that there is a tendency of a high impact for reduction in water availability in Southern Portugal at the end of the 21st century (year 2100) as projected by climate models (SHETRAN) used in the study.

4.0 Global Climate Models (GCMs)

In climate change impact studies, hydrological models are needed to have high competency in simulating the current and future climates at sub-grid scale phenomenon. The Global Climate Models (GCMs) are the most commonly used tools in simulating the present and future climates for climate change studies. In general, these GCMs are able to simulate the detailed global and regional climate systems, and thus provide a reasonable representation of the global climate (Chiew *et al*, 2010).

However, the GCMs have the properties of spatial and coarse resolution of reaching up to 300 km (Solomon, 2007) in determining the local climate change effects. In general, such high resolution is unable to be used in purpose of representing large watershed features and dynamics of the watersheds (Wigley *et al*., 1990; Carter *et al*., 1994). Moreover, GCMs are unable to provide the direct estimation of hydrological responses to climate change, not capable to provide hourly or daily rainfall and often biased representation (Segui *et al*., 2010).

Therefore, due to the model's incompetency, the outputs from GCMs must be recalculated by using appropriate resolution for better and more accurate analysis (Nasseri *et al*., 2013). Various methods involving the use of hydrological models had been integrated to obtain catchment-scale climate series for simulations for the current and future climates. The methods include the downscaling techniques, which are used to convert the regional scale meteorological variables from GCM outputs into a reliable daily rainfall series at the selected watershed scale to produce better and more reliable result (Nasseri *et al*., 2013).

4.1 Downscaling Techniques

The downscaling techniques are used mainly to derive the GCM outputs into a more reliable rainfall series corresponding to future climates (Dibike and Coulibaly, 2005). The techniques can be either dynamical or statistical (Mearns *et al*., 1999 and Segui *et al*., 2010). Dynamical and statistical downscaling methods are often presented as mutually exclusive but they can still be used together.

Dynamical models are commonly used to extract local-scale information from large-scale GCM data, by using the limited area models (LAMs) or regional climate models (RCMs) with relatively lower resolution of 25 km or 50 km compared to GCMs (Segui *et al*., 2010). The studies on climate change impact with RCMs had been proven successful to numerous studies in different regions (Giorgi, 1990; Giorgi and Mearns, 1991; Giorgi *et al*., 1990; Jones *et al*., 1995; and Jenkins and Barron, 1997). The main limitations of the dynamic modelling are that RCMs still require the computing resources, highly expensive to run, and these models still require the need to downscale the results from such models to individual sites or localities for impact studies (Wilby and Wigley, 1997).

On the other hand, the statistical downscaling methods (SDMs) generally provides hydrological useful regional algorithms and plays the important role in translating global climate change scenarios to more regional impact assessment (Xu, 1999). This method involves the study of empirical relationships and the correlation between global GCM meteorological variables and local meteorological variables. SDMs can be applied either by direct downscale local surface climate variables from large scale climate variables simulated by GCMs or from variables that are downscaled from GCMs using RCMs (Hundecha *et al*., 2016). Most of the studies that implemented statistical downscaling to RCM simulations used methods that are broadly categorized as change factor and bias correction methods as studied by Graham *et al*., (2007), Lenderink *et al*., (2007), Hurkmans *et al*., (2010), Rojas *et al*., (2012) and Ott *et al*., (2013).

The site conditions and the variables of interest are the main factors in choosing the suitable statistical downscaling methods (Hundecha *et al*., 2016). Statistical downscaling methods such as multiple linear regression, nonlinear regression and stochastic weather generators are most preferred by many researchers in anticipating hydrologic impact studies under climate change scenarios. According to Xu (1999) and Nasseri *et al*. (2013), these methods are much easier and less costly to develop and implement, compared to dynamical downscaling techniques that required limited-area models (LAMs) or regional climate models (RCMs). The details on advantages and disadvantages of using the statistical regression based downscaling methods had been explained by Hessami *et al*. (2008).

Statistical downscaling model (SDSM) is the most popular model used by researchers, and the most cited concepts and packages among regression based statistical downscaling methods (Nasseri *et al*.,2013 and Khan *et al*.,2006). The model basically often uses a multiple regression-based method that is developed from large-scale predictor variables and local scale predictors such as temperature and precipitation. The dual simplex algorithms are used in determining the parameters of the regression equation. For this model, the daily precipitation is modelled as conditional process to enable the researcher to correlate the local precipitation amounts with the occurrence of wet days, which in turn correlate with large scale atmospheric variables. Meanwhile, the temperatures are modelled as unconditional parameter in SDSM between the large and local scale parameters. The daily precipitation and temperature downscaling for the model are structured as monthly model and thus twelve regression equations are derived for twelve months (Khan *et al*., 2006).

The other commonly used downscaling model is a stochastic weather generator called Long Ashton Research Station Weather Generator (LARS-WG) as stated by Semenov and Barrow (1997). Compared to SDSM, large-scale predictor variables are not directly used in the LARS-WG model but instead, it need to be adjusted to local station climate variables by considering the monthly changes in mean daily precipitation amount, daily wet and dry series duration, mean daily temperature and temperature variability between current and future periods predicted by a GCM. Besides, the monthly precipitation data for LARS-WG are analysed based on the historical data to obtain statistical characteristics such as number of dry days, wet days and mean daily precipitation in each month of a year. Same as SDSM, precipitation modelling in LARS-WG is also a two-step process conditioned on wet and dry-days. However, unlike SDSM, temperature modelling for LARS-WG is modelled as conditional process in which, conditioned on dry and wet status of the days.

There are lots of other methods available such as Artificial Neural Networks (ANNs), Support Vector Machine (SVM), Model Tree (MT), Multivariate Adaptive Regression Splines (MARS) and other linear regression methods. These methods have been used in the previous studies for climatological research, but they are not very common compared to SDSM and LARS-WG methods. It is because those two methods are very easy to handle and produce the most reliable results compared to others (Nasseri *et al*., 2013).

5.0 Discussion

Two types of statistical (a stochastic and a regression based) downscaling techniques were applied by Dibike and Coulibaly (2005). The results obtained from both methods are different, but there is an increase in mean daily temperature values. Meanwhile, the variability of daily precipitation values for regression based method is more obvious compared to stochastic weather generator.

Besides, there were lots of studies conducted by researchers in purpose of comparing and determining the aspect of uncertainty of those downscaling models. Khan *et al*. (2006) concluded that the SDSM is the best statistical downscaling model, followed by LARS-WG and the ANN. This is because SDSM is found to be capable in generating almost all downscaled statistical characteristics with 95% confidence level which is the highest value compared to two other models.

There are various downscaling techniques available that are applied in climate change impact studies. However, it is still not clear which methods can give the most reliable estimates of daily rainfall time series, since the study on this topic are still in a developmental stage and unable to produce the definitive answers. Xu (1999) and Segui *et al*. (2010) stated that the results from the studies by different types of models had been found in consistency, but the result was unable to be fully verified as all of the modelling procedures involved in the assessment of the impact of climate change had their own element of uncertainty (Meehl *et al*., 2000). Therefore, the future climate change impact study must look at all kinds of uncertainty related to the GCM in assessing the level of confidences (Christensen and Lettenmaier, 2006; Hamlet and Lettenmaier, 1999; Maurer and Duffy, 2005; Minville *et al*., 2008).

6.0 Conclusion

A change in climate can directly affect many components related to hydrological cycle, such as water resources systems, ecological systems, local climate, and human activity (Nan *et al*., 2011). The main reason on how climate change greatly affected the water resources is when there are changes in water quantity and water quality (Raneesh, 2014). Impact of climate changes will be the revision for hydrological cycle, and this will greatly affected the amount and quality of regional water resources. According to Dibike and Coulibaly (2005) insights from GCMs, the output was recalculated by appropriate resolution for better and more accurate analysis.

The climate change impacts at local scale are necessary and play fundamental role to downscaling the global data, by working through statistical and dynamical methods (Mearns *et al*., 1999 and Segui *et al*., 2010). Statistical downscaling model (SDSM) is the most popular and the most cited model among regression based statistical downscaling methods (Nasseri *et al*., 2013 and Khan *et al*., 2006). On the other hand, dynamic downscaling develops a regional climate model (RCM) with the course GCM data for use as boundary conditions. Wilby and Wigley (1997) stated that the major limitations or disadvantages of the dynamic modelling are that it is quite complicated as it require the computing resources, take longer simulation time, high operating cost and above all, require the downscaled data for individual sites or localities for impact studies. Statistical downscaling techniques are usually the more favourable and much easier techniques for the assessment of climate change impacts on water resources (Khan *et al*., 2006). However, the projections of future climate impacts should look at all aspects of uncertainty related to the GCM in determining the level of confidences.

7.0 Acknowledgements

The authors acknowledge the research grant provided by Universiti Teknologi Malaysia (UTM) under GUP Tier 2 (Vote No: 12J76/2016).

References

Anderson, L., Samuelsson, P., and Kjellstrom, E., (2011). Assessment of climate change impact on water resources in the Pungwe river basin, *Series a Dynamic Methodology and Oceanography: Tellus*, 63A, 138-157.

Arheimer, B., Donnelly, C., and Stromqvist, J. (2013). Large-Scale Effect of Climate Change on Water Resources in Sweden and Europe, *Journal of Water Management and Research*, 69, 201–207.

Bates, B. C., Kundzewicz, S. W., and Palutikof, J. P., (2008). Climate change and water. Technical paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

Beare, S., and Heaney, A. (2002). Climate change and water resources in the Murray Darling Basin, Australia-Impacts and possible adaptation, *In: 2002 World Congress of Environmental Economists*, Monterey, California, June 24-27.

Bigas, H. (Ed.), 2012. The Global Water Crisis: Addressing an Urgent Security Issue. Papers for the Inter Action Council, 2011-2012. Hamilton, Canada: UNU-INWEH.

Carter, T. R., Parry, M. L., Harasawa, H., and Nishioka, S. (1994). IPCC technical guidelines for assessing impacts of climate change. *Intergovernmental Panel on Climate Change, WMO and UNEP, Geneva*, 59.

Chiew, F. H. S., Kirono, D. G. C., Kent, D. M., Frost, A. J., Charles, S. P., Timbal, B. and Fu, G. (2010). Comparison of runoff modelled using rainfall from different downscaling methods for historical and future climates. *Journal of Hydrology*, *387*(1), 10-23.

Christensen, N., and Lettenmaier, D. P. (2006). A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin. *Hydrology and Earth System Sciences Discussions*, *3*(6), 3727-3770.

Cunha, L. V., Oliveira, R.P., Nascimento, J., and Ribeiro, L. (2007). Impacts of Climate Change on Water Resources: a case study for Portugal. Proceedings of the Fourth Inter Celtic Colloquium on Hydrology and Management of Water Resources, International Association on Hydrological Sciences, pub. 310, Guimarães, Portugal.

Demuth, S., and Radojevic, B. (2011). Global Change and its Impact on Water Resources: the Role of UNESCO's International Hydrological Programme, *Water Research and Management*, Vol. 1, pg. 7-15.

Dibike, Y. B., and Coulibaly, P. (2005). Hydrologic impact of climate change in the Saguenay watershed: comparison of downscaling methods and hydrologic models. *Journal of hydrology*, *307*(1), 145-163.

Fowler, A. (1999). Potential climate change impacts on water resources in the Auckland. *Climate Research*, Vol. 11: 221–245.

Giorgi, F. (1990). Simulation of regional climate using a limited area model nested in a general circulation model. *Journal of Climate*, *3*(9), 941-963.

Giorgi, F., and Mearns, L. O. (1991). Approaches to the simulation of regional climate change: a review. *Reviews of Geophysics*, *29*(2), 191-216.

Giorgi, F., Marinucci, M. R., and Visconti, G. (1990). Use of a limited-area model nested in a general circulation model for regional climate simulation over Europe. *Journal of Geophysical Research: Atmospheres*, *95*(D11), 18413-18431.

Graham, L. P., Andréasson, J., and Carlsson, B. (2007). Assessing climate change impacts on hydrology from an ensemble of regional climate models, model scales and linking methods–a case study on the Lule River basin. *Climatic Change*, *81*(1), 293-307.

Hamlet, A. F., and Lettenmaier, D. P. (1999). Effects of climate change on hydrology and water resources in the Columbia River basin. *JAWRA Journal of the American Water Resources Association*, *35*(6), 1597-1623.

Hellmuth, M., and Kabat, P. (2003). *In: Climate changes the water rules; how water managers can cope with today's climate variability and tomorrow's climate change.* (pp. 26-43). Dialogue on water and climate.

Hessami, M., Gachon, P., Ouarda, T. B., and St-Hilaire, A. (2008). Automated regression-based statistical downscaling tool. *Environmental Modelling and Software*, *23*(6), 813-834.

Houghton, J. T.,Meira Filho, L. G., and Caccander, B. A.. (1995). IPCC Climate change 1995, the Science of Climate Change Cambridge. Cambridge University Press, UK.

Hundecha, Y., Sunyer, M. A., Lawrence, D., Madsen, H., Willems, P., Bürger, G., and Vasiliades, L. (2016). Inter-comparison of statistical downscaling methods for projection of extreme flow indices across Europe. *Journal of Hydrology*, *541*, 1273-1286.

Hurkmans, R., Terink, W., Uijlenhoet, R., Torfs, P., Jacob, D., and Troch, P. A. (2010). Changes in stream flow dynamics in the Rhine basin under three high-resolution regional climate scenarios. *Journal of Climate*, *23*(3), 679-699.

IPCC (2013). Intergovernmental Panel on Climate Change "About Stochastic Weather Generators". Retrieved from http://www.ipcc-data.org/ddc_weather_generators.html

Jeevaragagam, P., and Simonovic, S.P (2013). "Improvement of stream flow simulation for Gauged site of Hydrological Model." *Malaysian Journal of Civil Engineering* (MJCE) 25(2), 239-253.

Jeevaragagam, P., and Simonovic, S.P (2012). "Neural network approach to output updating for the physically based model of the Upper Thames River watershed." *International Journal of Hydrology Science and Technology (IJHST)*, 2(3), 306-324.

Jenkins, G. S., and Barron, E. J. (1997). Global climate model and coupled regional climate model simulations over the eastern United States: GENESIS and RegCM2 simulations. *Global and Planetary Change*, *15*(1), 3-32.

Jones, R. G., Murphy, J. M., and Noguer, M. (1995). Simulation of climate change over Europe using a nested regional-climate model. I: Assessment of control climate, including sensitivity to location of lateral boundaries. *Quarterly Journal of the Royal Meteorological Society*, *121*(526), 1413-1449.

Khan, M. S., Coulibaly, P., and Dibike, Y. (2006). Uncertainty analysis of statistical downscaling methods. *Journal of Hydrology*, *319*(1), 357-382.

Lenderink, G., Buishand, A., and Deursen, W. V. (2007). Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. *Hydrology and Earth System Sciences*, *11*(3), 1145-1159.

Maurer, E. P., and Duffy, P. B. (2005). Uncertainty in projections of stream flow changes due to climate change in California. *Geophysical Research Letters*, *32*(3).

Mearns, L. O., Bogardi, I., Giorgi, F., Matyasovszky, I., and Palecki, M. (1999). Comparison of climate change scenarios generated from regional climate model experiments and statistical downscaling. *Journal of Geophysical Research: Atmospheres*, *104*(D6), 6603-6621.

Meehl, G. A., Boer, G. J., Covey, C., Latif, M., and Stouffer, R. J. (2000). The coupled model inter comparison project (CMIP). *Bulletin of the American Meteorological Society*, *81*(2), 313-318.

Minville, M., Brissette, F., and Leconte, R. (2008). Uncertainty of the impact of climate change on the hydrology of a nordic watershed. *Journal of hydrology*, *358*(1), 70-83.

Mourato, S., Moriera, M., and Corte-Real, J., (2015). Water Resources Impact Assessment Under Climate Change Scenarios in Mediterranean Watersheds, *Water Resources Manage*, 29, 2377-62391.

Nan,Y., Bao-Hui, M., and Chun-kun, L., (2011). Impact analysis of climate change on water resources, *Procedia Engineering*, 24, 643-648.

Nasseri, M., Tavakol-Davani, H., and Zahraie, B. (2013). Performance assessment of different data mining methods in statistical downscaling of daily precipitation. *Journal of hydrology*, *492*, 1-14.

Ott, I., Duethmann, D., Liebert, J., Berg, P., Feldmann, H., Ihringer, J., and Wagner, S. (2013). High-resolution climate change impact analysis on medium-sized river catchments in Germany: an ensemble assessment. *Journal of Hydrometeorology*, *14*(4), 1175-1193.

Raneesh, K. Y. (2014). Impact of Climate Change on Water Resources. *Journal of Earth Science & Climatic Change*, *5*(3), 1.

Rojas, R., Feyen, L., Bianchi, A., and Dosio, A. (2012). Assessment of future flood hazard in Europe using a large ensemble of bias-corrected regional climate simulations. *Journal of Geophysical Research: Atmospheres*, *117*(D17).

Seguí, P. Q., Ribes, A., Martin, E., Habets, F., and Boé, J. (2010). Comparison of three downscaling methods in simulating the impact of climate change on the hydrology of Mediterranean basins. *Journal of Hydrology*, *383*(1), 111-124.

Semenov, M. A., and Barrow, E. M. (1997). Use of a stochastic weather generator in the development of climate change scenarios. *Climatic change*, *35*(4), 397-414.

Solomon, S. (Ed.). (2007). *Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge University Press.

Solomon, M. M. (2016). Effect of Climate Change on Water Resources. *Journal of Water Resources and Ocean Science*. Vol. 5, No. 1, 2016, pp. 14-21.

Smith, D. M. (2006). *Just One Planet: poverty, justice and climate change.* Rugby, England: Intermediate Technology Publications Limited, pg. 73.

Wigley, T. M. L., Jones, P. D., Briffa, K. R., and Smith, G. (1990). Obtaining sub-grid-scale information from coarse-resolution general circulation model output. *Journal of Geophysical Research: Atmospheres*, *95*(D2), 1943-1953.

Wilby, R. L., and Wigley, T. M. L. (1997). Downscaling general circulation model output: a review of methods and limitations. *Progress in Physical Geography*, *21*(4), 530-548.

WMO (1987) World Meteorological Organization, Water resources and climatic change: sensitivity of water resources systems to climate change and variability. Geneva: WMO.

Xu, C. Y. (1999). Climate change and hydrologic models: A review of existing gaps and recent research developments. *Water Resources Management*, *13*(5), 369-382.